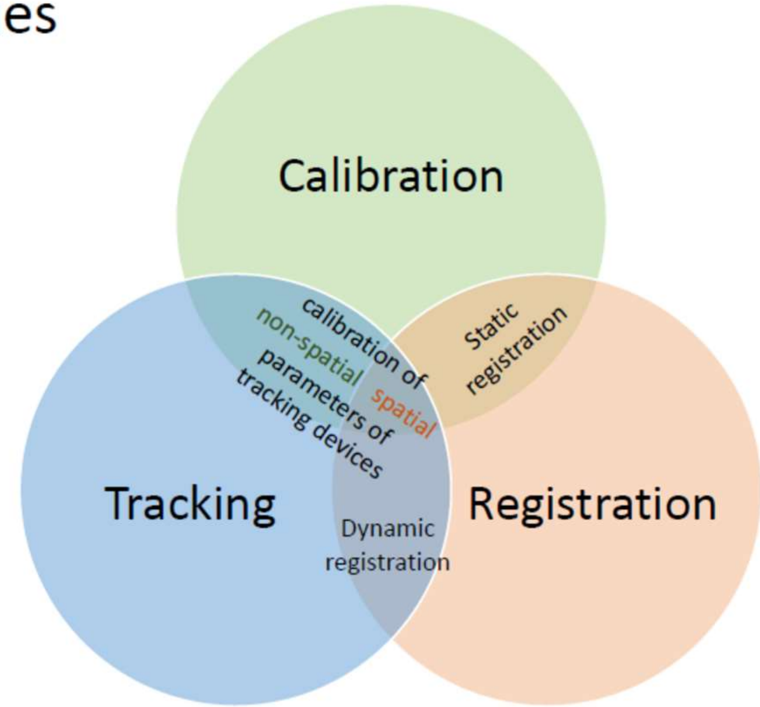
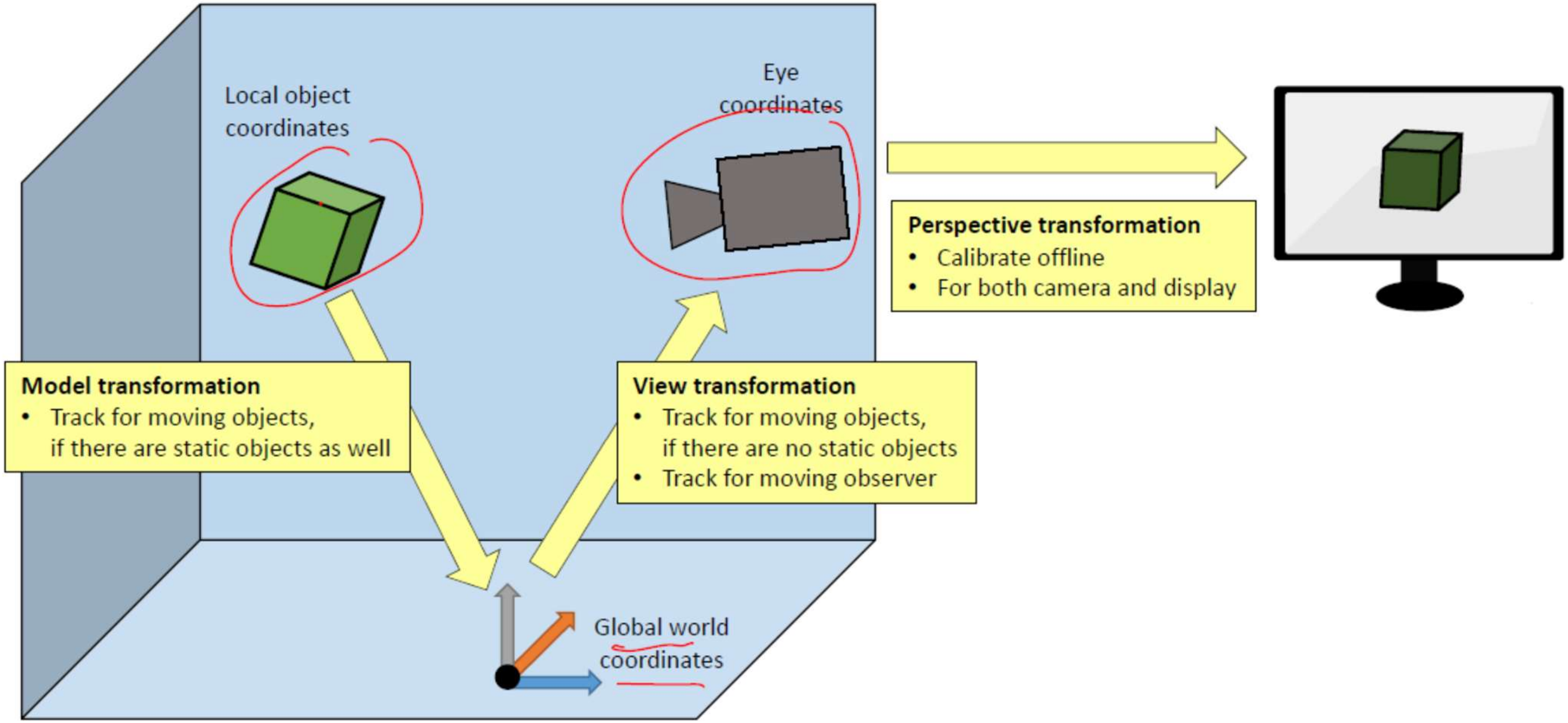
Tracking, Calibration and Registration

- Registration = alignment of spatial properties
- Calibration = offline adjustment of measurements
  - Spatial calibration yields static registration
  - Offline: once in lifetime or once at startup
  - Alternative: autocalibration
- Tracking = dynamic sensing and measuring of spatial properties
  - Tracking yields dynamic registration
  - Tracking in AR/VR always means “in 3D”!



Coordinate Systems



Model Transformation

- Relationship of 3D local object coordinates and 3D global world coordinates.
- Determines where objects are placed in the real world.
- Virtual objects are controlled by the application and do not require tracking, except in very rare situations.
- For every moving real object in the scene with which we want to register virtual information, we must track its model transformation.

View Transformation

- Relationship of 3D global world coordinates and 3D camera coordinates.
- Tracks for moving objects and moving observer
- Separate viewing transformation for the camera and the display of the user.
- If only a single camera needs to be tracked in a video see-through device, no display calibration may be necessary.
- Systems using stereoscopic displays may require calibration of camera and display.

Projective Transformation

- Relationship of 3D camera coordinates and 2D device coordinates.
- Content is mapped to a unit cube and projected onto the screen by dropping the Z component and applying a viewport transformation for correct aspect ratio
- Usually calibrated offline.
- Done for each camera and each display separately.

Characteristics of AR Tracking Technology

1

Latency

The delay between real-world and virtual object movements.

2

Accuracy

The level of precision in tracking the position position and orientation of objects.

3

Stability

The ability to maintain tracking over time and under different conditions.

Characteristics of Tracking Technology

1) Physical Phenomenon

- Measurements can exploit ***electromagnetic radiation*** (including visible light, infrared light, laser light, radio signals, and magnetic flux), sound, physical linkage, gravity, and inertia.
- Specialized sensors are available for each of these physical phenomena.

2) Measurement Principle

- Measure ***signal strength, signal direction, and time of flight*** (both absolute time and phase of a periodic signal).
- Time-of-flight measurements require some form of secondary communication channel to confirm clock synchronization between sender and receiver.
- Also measure ***electromechanical properties***.

3) Sensor Arrangement

- Use ***multiple sensors*** together in a known rigid geometric configuration, such as a stereo camera rig.
- Such a configuration can either be ***sparse***, if only a few sensors are used, or in the form of a **dense 2D array**, such as a digital camera sensor with millions of pixels.

4) Signal Sources

- Signal that is picked up by the ***sensors from sources*** positioned in a known geometric configuration.
- Sources can be either passive or active.
    - **Passive sources** rely on *natural signals* present in the environment, such as natural light or the Earth's magnetic field. When no external source is apparent, such as in inertial sensing - **Source less** sensing.
    - **Active sources** rely on some form of electronics to produce a *physical signal.*

5) Degrees of Freedom (DOF)

- DOF = independent dimension of measurement
- Full tracking requires 6DOF
    - 3DOF position (x, y, z)
    - 3DOF orientation (roll, pitch, yaw)
- Some sensor deliver only a subset
    - E.g., gyroscope → 3DOF orientation only
    - E.g., tracked LED → 3DOF position only
    - E.g., mouse → 2DOF position only

6) Measurement Error

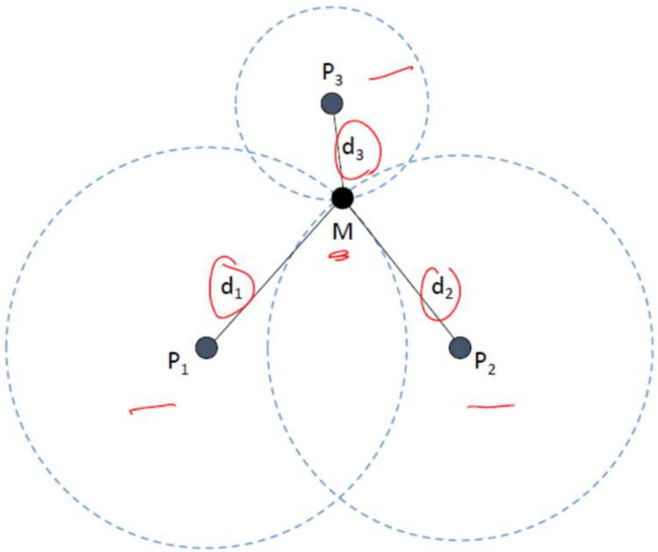
- Real-world sensors are subject to both systematic and random measurement errors.
- Systematic measurement error, such as a static offset, a scale factor error, or a systematic deviation from ideal measurements because of predictable or measurable influences of the environment can be addressed by improved calibration efforts.
- ***Accuracy, precision, resolution*** – error characteristics

7) Temporal Characteristics

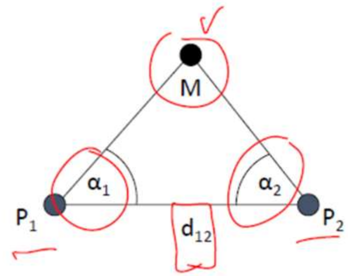
- **T**wo temporal characteristics - **update rate and latency**.
- **Update rate** (or temporal resolution) is the number of measurements performed per given time interval.
- **Latency** is the time it takes from the occurrence of a physical event, such as a motion, to a corresponding data record becoming available to the AR application.

8) Measured Geometric Property

- Trilateration: 3 distances



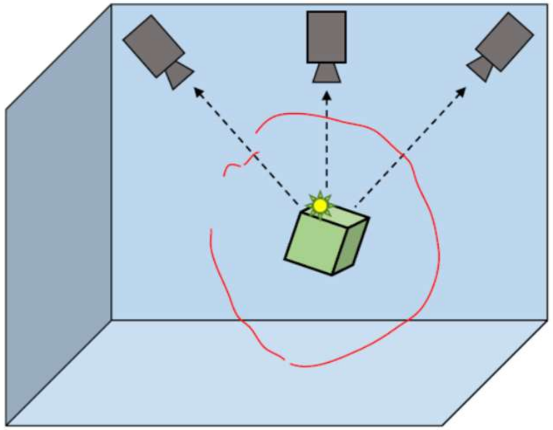
- Triangulation: 2 angles, 1 distance



9) Sensor Group Arrangement

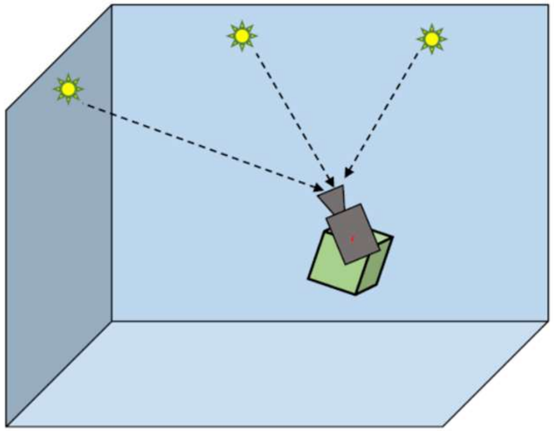
Outside-in

- Stationary mounted sensors
- Good position, poor orientation



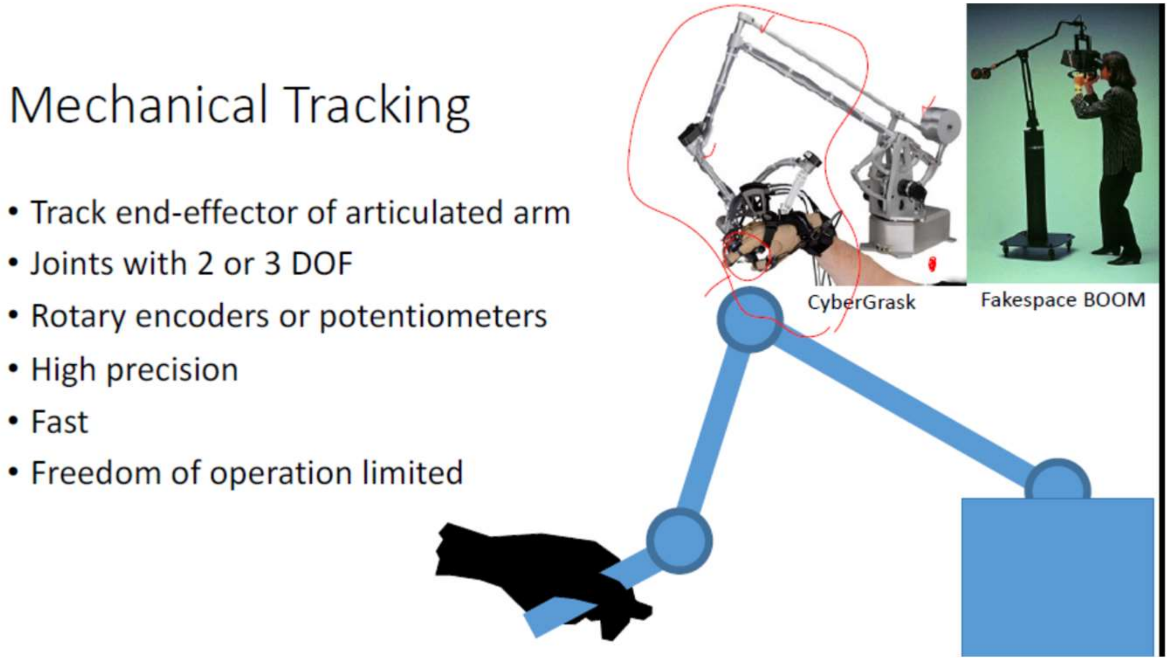
Inside-out

- Mobile sensor(s)
- Good orientation, poor position



Stationary Tracking

1. Mechanical tracking
2. Electromagnetic tracking
3. Ultrasonic tracking



Electromagnetic Tracking

- Stationary source produces three orthogonal magnetic fields.
- Position and orientation are measured simultaneously from magnetic field
- Strength and direction measured using small tethered sensors equipped with three orthogonal coils.
- Decreasing field strength with distance and tether length of the sensors typically limit the operating range to a hemisphere of 1-3 m diameter.
- **Ex: Razer Hydra**

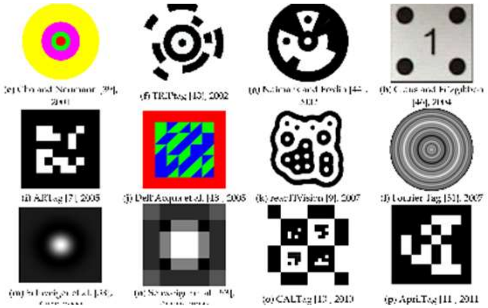
Ultrasonic Tracking

- Measures the time of flight of a sound pulse traveling from source to sensor.
- If a separate (wired or infrared) synchronization channel is available, three measurements are sufficient for trilateration.
- Multiple ultrasonic sensors can pick up a signal simultaneously, but sources must send their pulses sequentially to avoid interference.
- This limits the update rate to 10–50 measurements per second - must be shared for all tracked objects.
- Limitations: requirement of an open line of sight for clear reception, susceptibility to disturbances from loud environmental noises, and dependence of the speed of sound on air temperature
- **Ex: AT&T Bat system**

Other Stationary Tracking

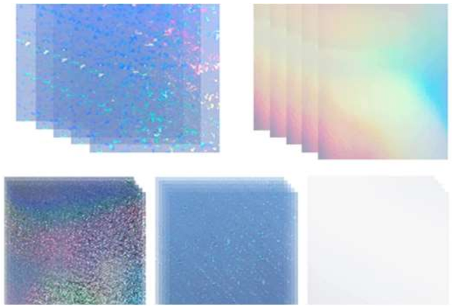
QR Code Tracking

Uses QR codes as reference points for tracking.



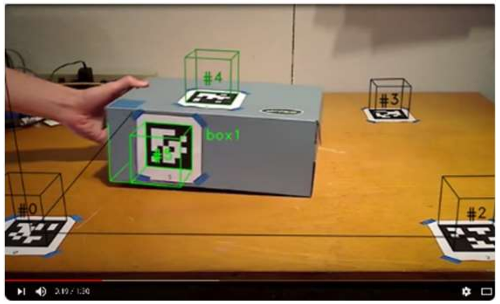
Fiducial Marker Tracking

Uses special markers with recognizable patterns.



Holographic Sticker Tracking

Reflects light in a unique way to enable tracking.



Multi-Marker Tracking

Uses multiple markers to more easily track complex objects.

Mobile Sensors

1. Motion Sensors
2. Environmental Sensors
3. Ambient Light Sensor
4. Proximity Sensor
5. Barometer Sensor
6. Pedometer Sensor
7. Hall Sensor
8. IR Blaster
9. **GPS**
10. **Magnetometer**
11. **Accelerometer**
12. **Gyroscope Sensor**
13. **Odometer**
14. **Wireless networks**

Non-visual sensors

Optical Tracking

1 Single Camera Tracking

Uses a single camera to track objects based on their visual features.

2 Depth Sensor Tracking

Uses a depth sensor to track objects based on their proximity to the camera.

3 Multiple Camera Tracking

Uses multiple cameras to triangulate object position and orientation.

Optical Tracking

- Determines *object position* by tracking active or passive infrared markers attached to the object.
- Uses visual information to track the user.
- Commonly make use of a *video camera* as an electronic eye to “watch” the tracked object or person.
- *Computer vision techniques* are then used to determine the object's position based on what the camera sees.
- **Aspect - Nature of the light.**
    - **Passive Illumination**: comprises light sources that are not an integral part of the tracking system.
    - Passive illumination comes both from natural light sources (sun), and artificial light sources (ceiling lights).
    - Conventional cameras see light in the visible spectrum (380-780 nm) reflected off objects in the environment.
    - Using a *conventional digital camera* with passive illumination is the simplest approach to optical tracking in terms of physical setup.

- **Active Illumination** overcomes the dependence on external light sources in the environment by combining the ***optical sensor*** with an active source of illumination.
- Because active illumination in the visible spectrum changes how the user perceives the environment and is therefore disturbing,
- Popular approach is to rely on ***infrared illumination***

- **Structured Light** goes one step further than active illumination with unstructured light sources by projecting a known pattern onto a scene.
- The source of the structured light can be a conventional projector or a laser light source.
- The observed reflections are picked up by a camera and used to detect the geometry of the scene and the contained object.

Sensor Fusion

1) Complementary Sensor Fusion

- occurs when multiple sensors supply ***different degrees of freedom***.
- No interaction between the sensors is necessary, other than combining the resulting data.
- Of course, this combination can still be nontrivial, if the sensors are not synchronized
- The most common use of complementary sensor fusion is to combine a position-only sensor with an orientation-only sensor to yield full 6DOF.
- For example, in a modern mobile phone, GPS delivers position information, while the compass and accelerometer deliver orientation data.

2) Competitive Sensor Fusion

- combines the data from different sensor types measuring the ***same degree of freedom*** *independently*.
- The individual measurements are combined into a measurement of superior quality using some form of mathematical fusion.
- *Redundant sensor fusion* is a simple variant of competitive sensor fusion.
- When the primary sensor is delivering measurements, secondary sensors are ignored. Only when the operation of a primary sensor is not possible does a secondary sensor take over. For example, poor or intermittent GPS reception.

3) Cooperative Sensor Fusion

- ***a primary sensor relies on information from a secondary sensor*** to obtain its measurements.
- GPS and compass technologies or accelerometers may be used as an index into a database of natural features, so that feature matching has a higher success rate.
- In a more general sense, cooperative sensor fusion can be described as any measurement of a property that cannot be derived from either sensor alone.

Applications of AR Tracking Technology

1 **Gaming** 🎮

Enhancing the gaming experience with realistic virtual objects and environments.

2 **Retail** 🛍

Enabling virtual try-on of clothing, accessories, makeup and more.

3 **Manufacturing** 🏭

Improving efficiency and accuracy of product assembly and maintenance through AR-guided visual instructions and remote assistance.

4 **Education** 🏫

Stimulating new ways of learning by providing immersive and interactive experiences that blend reality and digital information.